PSYCHOLOGY

LABORATORY COURSE

LABORATORY MANUAL OF PSYCHOLOGY

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VOLUME TWO

OF A SERIES OF TEXT-BOOKS DESIGNED TO
INTRODUCE THE STUDENT TO THE
METHODS AND PRINCIPLES OF
SCIENTIFIC PSYCHOLOGY

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PREFACE

The use of laboratory exercises in the teaching of psychology is a matter regarding which there is the widest divergence of opinion and practice in American institutions. In many colleges and normal schools, text-book courses pure and simple are the only courses offered. In other quarters a few typical experiments are demonstrated to the class as a whole. In a small number of institutions each student is given an opportunity at some time in his course for individual laboratory work.

The present volume is prepared with a view to facilitating the introduction of this last-mentioned form of instruction into a larger circle of institutions. The two questions which immediately arise in connection with such a course are, When should it be introduced, and what equipment is necessary to make it successful?

The matter of equipment is fully dealt with in another volume, and no detailed discussion need be given here. It is altogether appropriate to remark, however, that a successful laboratory course

in psychology requires only a very modest equipment, if one will confine himself to that which is absolutely essential. The essentials can be provided easily within the limits of $200, and even a smaller equipment can be made very productive in the hands of a skilful teacher.

The second question as to when individual laboratory work should be undertaken is less easy to answer. The exercises given in this book presuppose a knowledge of sensations, of perceptual processes, and of feelings. The necessary knowledge for intelligent use of the exercises can be derived from almost any one of the books in common use in introductory courses in psychology. The introductory course should ordinarily be at least half completed before the student is set at work in the laboratory. It will be found even better to postpone the laboratory work until the whole introductory course has been taken. The student will then begin the exercises with much greater comprehension of their value, and of the relation of the facts investigated to other facts of mental life. The introductory course may advantageously include demonstrations to the class of the experiments which the student is later to carry out in full; but careful experimental work, especially

when it is quantitative in character, cannot be expected before the student has acquired some general knowledge of the science.

Two other matters are touched upon in the introduction. First, the student should always be kept alive to the significance of his results. A required report and a general meeting of the class at which the experiments are discussed by all those who take part in the exercises are, according to the experience of the author, the most satisfactory devices for attaining this end. In certain of the exercises special preparation for the general class discussion may be made by appointing some member of the class to bring together in a general table the results of all who performed the exercise. All of these methods of procedure presuppose that the class will, in a given period, work at the same experiment. This may require a subdivision into small laboratory sections, or a duplication of apparatus; but the results of comparison and discussion will amply repay the instructor for the added effort and expense thus entailed.

The other matter to which explicit reference is here necessary, in addition to what is said in the introduction, is the typical character of all of the exercises. By means of the supplementary exer-

cises suggested, the flexibility of the course has been increased. It is quite possible to substitute one of the supplementary experiments for the main problem described in the text. If it is desired to devote more than one period to a given subject, the supplementary exercises may be assigned for a second, or in some cases even for a third period. In general, periods of laboratory work should be from two to two and a half hours in length. The exercises are prepared with such periods in view.

One general departure from the course as given in the text which the author has found to be very advantageous is as follows: When a student has gone through the first seventeen exercises, he may be allowed to select three others from the remaining eight, according to his own tastes. After thus becoming acquainted with the typical methods and problems, he should be allowed to devote the remainder of the time allotted to the course to a more complete study of some one problem. Some problem in practice, or some elaborate problem which requires more than one period, is especially suitable for this part of the course. Suggestions for such exercises will be found among the supplementary experiments, and in the references. In

preparing the references for readings, no effort has been made to secure completeness. Usually the references given contain further references which make it possible for the student to develop his own bibliography. The sole purpose of what is given is to encourage the student to compare the work of others with his own.

The obligations under which the author stands to those who have contributed in any way to this course are numerous. The course has been given in various degrees of elaborateness to eight classes. During the last four years it has been worked over into its present final form in Yale University, and in Columbia University during the summer session of 1904. During a part of this period, Dr. C. N. McAllister, as instructor in the Yale department, has been intimately associated with the course, and has contributed many suggestions to improve it. My present colleagues in psychology, Drs. E. H. Cameron and R. P. Angier, have read the proof and have also offered very valuable suggestions. Messrs. W. M. Steele, L. A. Weigle, D. J. Cowling, and F. N. Freeman, assistants in the Yale laboratory, and Dr. H. A. Ruger, assistant in the Columbia laboratory, participated in the conduct of the course, and in the reformulation of the exercises.

Other less personal obligations may be safely passed without explicit mention, as they will be obvious to those who are acquainted with the development of experimental psychology and courses of instruction in this subject.

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INTRODUCTION

The first step in a psychological experiment consists in producing a conscious experience under conditions which can be arranged and described with exactness. The second step consists in bringing about some clearly understood modification of the original conditions, and in recording as fully as possible any accompanying changes which appear in experience. There are two distinct advantages of experiment in psychology. In the first place, the constituent factors of experience become clearer as experience is repeatedly observed in the related and yet varying forms which are produced during the experiment; and, in the second place, all of the conditions of an experience can be determined by systematically introducing every possible variation of these conditions.

These general statements will be more fully understood if a concrete illustration is discussed in detail. Let an observer look at a straight, black, horizontal line, ten centimetres long, drawn on a large sheet of unruled paper, and held di-

rectly in front of the eyes at a distance of fifty centimetres. After examining the line and arriving at a clear perception of its length, let the observer hold it at the original distance and rotate it through ninety degrees, so that it comes into a vertical position. Let him again note carefully the apparent length of the line. If he observes no difference in the apparent lengths of the line in the horizontal and vertical positions, let him prepare somewhat more favorable conditions for comparison of the two positions by drawing on the same paper two lines each ten centimetres in length, one horizontal and the other vertical. He will now find that the two lines do not appear equal. Here is a fact of importance for the study of space perception. The apparent length of lines depends in some degree on their positions. Evidently the perception of length is a complex process, and some of the factors of the complex process are noticeably modified as the line is rotated from horizontal to vertical. The observer should use every means of discovering if possible the complete explanation of this fact. Can he observe any change in the content of experience, or any new distribution of emphasis among the factors of his percept, as he passes from one experience to the other? It is at

moments of sharp transitions in experience that observations of this sort are most easily possible. If no significant results appear after one observation, the experiment should be repeated.

The experiment may be carried further and the relation between the apparent length and the position of lines, which was established by the first observation, may be measured with exactness. The observer who notices under the conditions thus far described that vertical and horizontal lines are not perceived in the same way, will yet find it impossible to give an exact statement of the degree in which one line seems longer than the other. In order to secure an exact statement, more elaborate methods of recording the observer's experiences must be provided. Such methods may be provided as follows: Let the horizontal line be drawn as before, and let the observer be called upon to draw a vertical line which seems to him to be of just the same length as the standard horizontal line. Since lines which are equal do not seem equal, it follows that lines which seem to the observer to be equal will differ by some measurable quantity. The amount by which the lines differ when the observer regards them as equal is a convenient means of determining with quantitative exactness the relation

between the observer's experiences. The method is thus a very decided advance upon the general verbal statement that the equal lines seem unequal. It is possible, also, by this quantitative method to determine with exactness the variability of the observer's experiences. This can be done by taking a series of measurements instead of a single measurement.

In order to show the method of treating such measurements, the following typical table is presented, showing the lengths of ten vertical lines which were drawn by an observer when he was required to draw lines which seemed to him equal to a standard horizontal of ten centimetres in length. Column A shows the lengths of the successive drawings. The simple arithmetical average is set down below. Column B shows the amount by which each individual determination departs from the general average. These quantities are known as the variations, and their average, disregarding signs, is known as the mean variation. The mean variation in this case is small as compared

	A.	B.
I.—	8.6	.27
II.—	8.2	.13
III.—	8.1	.23
IV.—	8.7	.37
V.—	8.4	.07
VI.—	8.6	.27
VII.—	8.0	.33
VIII.—	8.1	.23
IX.—	8.2	.13
X.—	8.4	.07
Avg.	8.33	.210

Average difference between drawn line and standard, 1.67.

with the total difference between the standard horizontal line and the vertical lines drawn by the observer. The small mean variation shows that the difference in the apparent length of vertical and horizontal lines is due to some cause which is very constant and regular in its operation. Such definite knowledge of the variability of the observer's experiences would be quite impossible without a quantitative experiment.

The quantitative description of the facts does not, it is true, bring with it an explanation. Nor does it do away with the requirement that the observer study his own experience as carefully as possible while he is going through the test. Exact quantitative determination is only one method among many of describing experience. It should be used where it is possible, but should never be allowed to become a mechanical substitute for introspections.

This description of a typical psychological experiment prepares the way for a consideration of the important characteristics of all experiments. In the first place, it will be noted that the experience chosen for examination is a very simple experience, so simple, indeed, that it is intrinsically of little interest to the ordinary observer. The temp-

tation which most persons meet in beginning their psychological studies is the temptation of trying to deal first with very complex and especially interesting experiences. Striking experiences, however, seldom, if ever, fulfil the first requirement which should be kept in mind in selecting problems for experimental study, namely, the requirement of a clear-cut experience arising under definitely ascertained conditions. If, for example, instead of beginning with the observation of a single horizontal line, we should begin with a landscape or painting, or a complex geometrical figure, we should be involved at once in an experience so complicated that it would be impossible to make any determinations of difference such as were possible in the case chosen.

In the second place, it will be seen that experimental methods bring out characteristics of experience which would be overlooked under the ordinary conditions of observation. An observer looking at a single straight line, either horizontal or vertical, or at a miscellaneous group of lines running in various directions and having no prearranged equality of length, would not be conscious of the fact brought out in the experiment, that the apparent length of a line depends in part upon its

direction. The relation of length to direction can be observed only when experiences are presented in sharply contrasted forms and under conditions which facilitate comparison.

A third characteristic of experimentation is its natural development toward quantitative exactness. The question has been much discussed whether a measurement, such as that described in the illustration, is in any proper sense a measurement of experience. Should it not be described rather as a measurement of physical facts? Furthermore, it has frequently been pointed out that the degree of exactness attainable in dealing with such facts as those taken up in the experiment is much less than the degree of exactness attained in the physical sciences. The theoretical difficulties which have been emphasized by such discussions as these are not fatal to scientific psychology, as some have supposed. In answer to the first question it may be said that there can be no dispute as to the possibility of noting and recording a great many of the changes in experience which parallel the changes in external conditions. Whether it is to be called measurement when one arrives at such a description and comparison of experiences, or whether, for formal reasons, the process is called

by some other name, the psychologist may rest fully satisfied that he is arriving through experiment at a more complete, exact, and useful account of experience than he could otherwise obtain.

As to the criticism that psychological experiments are not as exact as the experiments of the natural sciences, the beginner is not likely to be concerned with any theoretical difficulties in the way of an exact mathematical formulation of experience. With him the difficulty is likely to assume a very practical and discouraging form. His variations will be so large that the significance of his measurements will seem in many cases questionable. The variations are, however, not mere obstacles in the way; they indicate much with regard to experience. The untrained observer has variations in excessive degree because he is easily distracted. He does not know how to give himself up to the observation of what is offered; he begins to speculate about his errors. He may have chosen an experience so foreign to his ordinary life that its very newness disturbs him. As he becomes more accustomed to experimental work, these disturbances tend to disappear. Every group of tests is thus, if properly interpreted, a series of observations of mental development, and the problem of

variations, though offering certain temporary difficulties, becomes an essential problem in psychology rather than a mere disturbance. The way to meet variations is to make them subjects of psychological analysis and explanation.

In general, then, we may conclude that the ideal of experimental psychology is a full, systematic, and as exact a study as possible of experience and its conditions. Whatever the difficulties in the way of theoretically absolute measurement, this practical ideal is always attainable, and has been most productive in the recent development of scientific studies of mental life.

In the experiment described above, no apparatus beyond pencil and paper was required. Special apparatus might have been employed to advantage. Thus instead of requiring the observer to draw the vertical line, let him be supplied with a simple apparatus in which a black wire passes through a hole in a card or sheet of paper, and is pushed up or down from behind, so as to make visible only so much as the observer desires. The task of the observer is now somewhat simplified, and consists in setting the wire so that the vertical portion which is visible seems to him equal to a horizontal standard. The adjustable wire may be

attached to a scale which will facilitate measurement; or a recording device may be arranged to indicate automatically how much of the wire has been exposed. There is no limit except that dictated by practical economy to the refinements which may be introduced into apparatus. Whatever is devised, however, the apparatus always remains an accessory. It is an external matter and should never be confused with the true motive of the experiment. The experiment is primarily concerned with experience and its conditions, not with mechanical appliances. Better no apparatus with a clearly defined experience and a thoroughly understood series of modifications of the experience, than the most elaborate apparatus and vagueness as to the problem under investigation.

It remains to take up in this introduction certain general practical matters. In most cases a psychological experiment requires two persons, one whose experience is the subject of examination, and one who controls the objective conditions. The most complete coöperation can be effected by requiring both persons to take alternately each rôle in the experiment. Such alternation has the double advantage of giving both persons a first-hand acquaintance with every phase of the experiment,

and it also relieves the tendency to fatigue, which is a serious complication when it appears on the part of the person whose experience is being tested. For convenience in discussions and records, the person who conducts the objective side of the experiment should always be designated as the experimenter. The person whose experience is being examined is variously designated as observer, reactor, or subject.

In the exercises of this course, a regular order of presentation will be followed. Under five general heads, the successive steps of preparation, experimentation, and elaboration of results will be outlined.

First, brief introductory remarks will be given, which will indicate to the student the general relations of the problems to be investigated. It is important that the student take up every investigation with a full knowledge of the meaning of the problem, otherwise his experimentation is likely to become a purely formal routine.

Second, some description will be given of the method to be followed in working out the problem. In this part of the exercise little, if any, reference will be made to apparatus, although apparatus is often required. The omission of any description

of apparatus is due to the fact that the general method is capable of adaptation, in most cases, to a variety of mechanical accessories, and the mechanical details can very properly be left to be demonstrated at the beginning of the experiment, or they can even be left to the student's own ingenuity.

Third, the exercise proper will conclude with certain questions which are intended to suggest to the student some of the lines along which he may utilize his results for psychological generalization, or for the formulation of new problems. It is especially important in this connection that the student recognize that science must always go further than the mere accumulation of experimental results. A fact ascertained in the course of an experiment is always the beginning rather than the culmination of science. The questions set down in the exercises are intended to stimulate to interpretation. They should not be so used as to restrict the student's discussions. They are intended merely as suggestions. The investigator's interest once aroused, should carry him along manifold other lines of interpretation.

Fourth, certain additional problems will be mentioned which stand in direct relation, either to the

method or matter of the problem set in the exercise. These are given to make clear to the student the typical rather than exhaustive character of the exercises of the course.

Fifth, a few reading references will be added, which may be used further to enlarge the scope of the student's acquaintance with problems cognate to the exercise.

Before beginning any exercise in the laboratory, the student should make himself familiar with the first three sections of the text for that exercise. He should then perform the experiment, making complete records of the results. The beginner is likely to neglect this matter of records. He feels so well acquainted with the results at the moment that they are being collected that he writes them down in some incoherent form with the idea of arranging them later. This is a great mistake. All material should be marked so that it will be intelligible even to one who did not see it collected. The date, title of the experiment, and the names of experimenter and observer should always be given. The nature of the experiment, and the order of collecting results should be clearly indicated. Where possible the successive results should be put in orderly columns ready for averaging or easy

comparison. The student will find that the time is well spent which he devotes at the beginning of an exercise to the preparation of a skeleton table in which to enter his results.

After finishing the exercise, the results should be formulated so as to bring out as fully as possible their meanings. The tables used during the collection of the results should be worked over; where possible, averages should be computed and general tables made up. Where graphic representations of the results are possible they are of great value in rendering a large body of facts easy of immediate comprehension.

After working over the results of the experiment, the student should prepare a report. This report should contain (1) a description of any apparatus employed and a critical discussion of the method. Any difficulties encountered in the use of the method and any desirable modifications should be fully stated. The report should contain (2) the results in tabulated or graphic form. It should contain (3) some discussion of the general significance of the results and of any new problems to which the author of the report has been led in the course of his work. The questions set down in

the text should not be answered one by one, but they should be used in a general way to arouse a train of discussion in the mind of the individual student. Especially should the student avoid introducing here in an uncritical way any of the formal theories which he finds in text-books. It is by no means out of place to discuss these theories and even agree with them on the basis of the results obtained in the course of the experiment. But it should constantly be borne in mind that just such results as the student has himself obtained lie at the foundation of every author's discussions, and the validity of every interpretation offered anywhere is to be tested by experimental facts. The student should be independent in the treatment of his results. It is in gaining this ability to interpret results independently that he will get his best scientific training. The performance of an experiment is merely preliminary to the scientific evaluation of the outcome of the experiment.

Finally, the report should discuss briefly one of the additional problems in order to give some training in the wider application of the method employed. In this connection the student should realize that each exercise of this course is typical of

a great number of related experiments. The progress of psychology depends in large measure upon the application of well-developed methods to as wide a range of problems as possible.

EXERCISE I

QUANTITATIVE STUDY OF GEOMETRICAL OPTICAL ILLUSIONS

Geometrical figures so drawn that certain lines within them are misinterpreted in respect to length or direction furnish very favorable subjects for psychological experimentation. The fact that the lines are misapprehended serves to concentrate attention at once on the difference between objective lines and subjective perceptions. The distinctly psychological character of the investigation is accordingly obvious from the first. Furthermore, geometrical figures lend themselves readily to exact description and easy adjustment, so that measurements can be made with a maximum of exactness and a minimum of distraction.

One of the most striking optical illusions is the Müller-Lyer illusion. The form of this illusion, represented in Fig. 1, may be used without difficulty for quantitative determinations. Let the line *A* and its enclosing obliques be drawn on a card so

that the point x will be at the edge of the card. On a second card let a long horizontal line be drawn with oblique lines extending outward at its left extremity. Place the first card over the second and bring the two long lines together so that they will stand in the relation *A B* shown in the figure. Move the upper card to the right or left, thus varying the length of *B*, until the lines *B* and *A* seem to the observer to be equal. Measure the amount by which *B* differs from *A*, and the result will con-

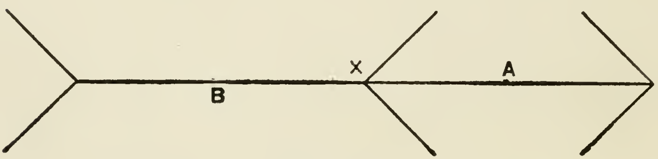

Fig. 1.

stitute a quantitative determination of the illusion for the observer who set the lines. Ten determinations should be made, five beginning with *B* apparently longer than *A*, five with *B* apparently shorter.

In the course of these determinations the observer should constantly be on the watch for introspections with which to supplement his measurements. Let him note the degree of certainty with which he makes the comparison of *A* and *B*. Let him attempt to discover what factors of experience

are involved in estimating the length of the lines. Does lengthening the line *B* give rise to an essentially different form of experience from shortening it?

After making ten determinations with the first form of the figure, modifications of the figure should be introduced and new series of determinations made. Thus, changes may be made in the length of the obliques, in the angle between the obliques and the long lines, in the position and distance of the figure with respect to the observer. By means of these and other variations, the influence of different parts of the figure in producing the illusion can be measured with precision.

In each case, after ten determinations have been completed, the average and mean variation should be computed.

In discussing the results of these experiments in the report, it should be shown in detail:

(1) That the estimation of the length of lines is influenced by the surroundings of the lines;

(2) that the perceptual interpretation of lines cannot be fully accounted for by referring merely to the retinal impressions of these lines;

(3) that perceptual recognition is different from theoretical knowledge, and is not directly under the influence of volition.

How far do the results of this experiment justify the statement that perceptual processes are complex, even when they seem to ordinary introspection to be simple?

What is space?

The report should further indicate how the method employed in this exercise might be extended to one of the following cases:

If a straight oblique line is entirely covered up in its middle portion by some object, the two exposed parts of the interrupted line do not seem to be continuous.

When two figures of like form but of different sizes, as, for example, two squares or two circles, are brought near each other in the field of vision, a point placed half-way between them does not appear to be equally distant from both of the figures.

When a straight line is crossed by numerous short lines, perception is complicated. In some cases this complication results in a misapprehension of length, in others in a misapprehension of direction.

The visual perception of savages has been found to be different from that of civilized adults.

Illusions of certain types have been found to grow less marked when they become more familiar.

A complete description of geometrical illusions and an elaborate bibliography will be found in Sanford's "Course in Experimental Psychology," pp. 212–60. A series of experimental studies will be found in "The Yale Psychological Studies, New Series," vol. i, pp. 55–139. Some discussions of the psychological character of illusions are given in Stratton's "Experimental Psychology and its Bearing upon Culture," pp. 95–164, and in the author's "Genetic Psychology for Teachers," pp. 10–31.

EXERCISE II

CHARACTERISTICS OF THE DIFFERENT PARTS OF THE RETINAL FIELD

An observer looking steadily at the centre of a large, uniformly colored field of vision would undoubtedly be disposed to consider his experience of the colored surface as very simple and direct. There is no obvious suggestion, as in the case of a recognized illusion, that there is a difference between impression and perceptual interpretation. In this case, however, quite as much as in the perceptual process taken up in the first exercise, a systematic experimental examination of the experience will reveal its complexity and will bring out clearly the difference between sensation and perceptual interpretation.

Let the observer cover one eye and fixate steadily with the open eye a clearly marked point in the centre of a uniform gray field of vision. Let the experimenter bring into the extreme outer part of the observer's field of vision a small colored area.

Beginning with such an area at the outer limit of the field of vision, let the experimenter move it inward by stages of ten degrees toward the point of fixation. At each stage the observer should describe fully the apparent color and brightness of the area.

It will be found in the course of the experiment that there is a very strong tendency to move the eye away from the centre of fixation toward the colored area. This tendency must be resisted by the observer because the regular movement of the image across the retina and the exact determination of the position of the image on the retina at any given time depend on steady fixation of the eye.

After the experiment has been tried in the way prescribed—that is, by moving the colored area inward toward the centre of the field of vision—let the direction of movement be reversed and let the observer see and describe the appearance of the colored area as it moves outward toward the edge of the field of vision.

The experiment should be made under exact quantitative conditions. First, the area shown to the observer should be of known size and of definite quality and intensity. Second, observations should be made at regular intervals of five degrees

from the outer limit of the field of vision to the centre of fixation along some definite line. Third, each color should be used three times in an order unknown to the observer, so as to find out the degree of possible variation in the observations. The record of the observer's experiences must in this case be verbal. It can, however, be made very definite by requiring him to describe each stage of experience in terms which compare it with the stage immediately preceding it. The colored areas should be varied to some extent in quality, at least four different colors (red, yellow, green, and blue) being used in the course of the exercise. The various colors used should be of like intensity.

In the report, a comparison should be made of the series of experiences derived from the various colors.

Also consider the following questions:

(1) How can the facts brought out in the experiment be reconciled with the ordinary experience derived from the examination of a large colored surface?

(2) What inferences may be drawn from this experiment regarding different parts of the retina?

(3) What is the advantage to an individual of possessing a sense organ with the characteristics thus discovered in the retina?

(4) What does this experiment show regarding the relation between sensations and the external stimuli to which sensations are related?

Show, also, how one of the following related problems could be attacked.

There is an area in every monocular field of vision which we do not see at all without moving the eye. How can the position and form of this area be determined?

A long straight line passing vertically through the edge of the field of vision will seem to be curved. How can the direction and degree of apparent curvature in different parts of the field be measured?

By a method analogous to that used with colors, determine the ability of different parts of the retina to give sensations leading to clear recognition of forms such as circles, triangles, squares.

The sensitivity of different parts of the retina for slight changes in intensity of illumination is not the same. How can this variation in sensitivity be measured?

If the observer sits for a time in a dark room so that his retina becomes adapted to darkness, it can be shown that the changes in sensitivity at the periphery and centre of the retina are very different.

An excellent summary of all the investigations of the type referred to in this exercise is given in Baird's "The Color Sensitivity of the Peripheral Retina," a publication of the Carnegie Institution. A very complete account of the facts is also given in the article "Vision," in Baldwin's "Dictionary of Philosophy and Psychology."

EXERCISE III

COLOR SENSATIONS

In the second exercise it was shown that the centre of the retina is more highly differentiated in its responses to colors than is the periphery of the retina. In this exercise further investigation of the most highly developed responses to color will be undertaken for the purpose of showing more fully what is the relation between physical stimulation and experience.

Let the observer look steadily, with as little movement of the eye as possible, at a colored area about ten centimetres square. After looking for a full minute at a given color, let him look at a gray surface and note the after-effects of the color stimulation. This process should be repeated for all of the chief colors: red, orange, yellow, green, blue, violet, and purple.

Secondly, let the eye be stimulated by a mixture of colored lights. This part of the experiment can

be carried out with quantitative exactness. Take disks of colored paper which can be made to rotate rapidly and make up circles with variously colored sectors. These circles should be rotated fast enough to give the observer the impression of a uniform field in which there is no tendency to flicker. Find the number of degrees of each color necessary to make the combinations on the two sides of each of the following equations exactly match each other:

Red plus Yellow equals Orange plus Black plus White.
Red plus Green equals Yellow plus Black plus White.
Red plus Green-blue equals Black plus White.
Red plus Blue equals Purple plus Black plus White.
Red plus Green plus Blue equals Black plus White.
Yellow plus Blue plus Green equals Black plus White.
Orange plus Blue plus Green equals Black plus White.

The report on this exercise should consider the following questions:

How far is color experience a result of physical stimuli and how far is it determined by the laws of retinal behavior?

Do the equations of mixed colors show a relationship between physical colors or between retinal processes?

Is there any direct relationship between the results of this exercise and the results of the experiments described in the second exercise?

If one undertakes to formulate the facts derived from these experiments into a theory of color vision, what advantages will be derived from such a theory, and what are the requirements to which the theory must conform?

How could the following facts be systematically and quantitatively investigated?

(1) A color does not have the same appearance when placed upon different backgrounds.

(2) Certain color combinations which match each other in one intensity of light do not match in other intensities.

(3) As the intensity of simple colors is reduced or increased the quality changes.

(4) Pigments when mixed do not give equations similar to those derived from mixing colored lights.

A very good summary of the facts and theories of light sensations is given in Stout's "Manual of Psychology," pp. 141–70. A similar summary

with a great variety of exercises, which may be used to supplement the text, is given in Sanford's "Course in Experimental Psychology," pp. 147–68.

EXERCISE IV

MONOCULAR VISUAL EXPERIENCES

Ordinary vision is binocular. There are, therefore, two groups of sensations, one from the right eye and one from the left, involved in ordinary processes of visual perception. How these two groups of sensations fuse into a single experience is one of the much-discussed questions of psychology. In this exercise and the next the problem of visual fusion will be taken up, first by studying the character of the images which fall on the retinas of the two eyes, and second by investigating stereoscopic vision, which is a typical and easily controlled form of fusion.

1. Let the head of the observer be fixed in a rest and let one eye be covered. The experimenter should set up at a distance of four metres from the observer's eye a well-defined object, as, for example, a white paper on a black background. Let a measuring rod be placed successively at distances of one, two, and three metres across the direct line

between the object and the observer's eye and measure the distances on the rod which correspond in apparent length to the length and width of the object.

After the measurements are completed, draw to scale a figure representing all of the results.

2. Get a well-defined after-image of an object of known size and known distance from the eye. Project this image on a surface which is marked so that the apparent size of the projection can easily be measured. By this means measure the size of the projected after-image when it is projected to one, two, three, and four metres from the eye.

3. Let the observer sit with one eye closed, in a dark room, and let him look at an illuminated area the size of which is controlled by an Aubert's diaphragm. Change in irregular order the distance of the observed area from the observer and the size of the area, and require the observer to judge which change is made.

In the report let the following questions be answered:

(1) Does a retinal image have characteristics which unequivocally determine the distance of its source?

(2) If an object of a given size moves away from an observer, what will be the corresponding changes in the retinal image?

(3) Why does the projection of an after-image to different distances change its apparent size?

(4) Distinguish between sensation and perception, and show to what extent each is involved in the ordinary recognition of position and size.

The following supplementary problems may be suggested:

Let a pin be held before the open eye of an observer who has closed one eye. Let him attempt to bring a second pin directly over the first without bringing the two into direct contact. Let him then open the eye which was closed.

Let several threads be drawn at different depths through a box in such a way that no thread will seem to cross any other, and the ends will not be visible. Let an observer examine these threads first with one eye and then with two.

Let a card with a pin hole passing through it be held within a few centimetres of an observer's

eye. Let some objects such as a card or a pin be gradually moved up from below until it crosses the pin hole. Let this be done first on the side of the pin hole more remote from the eye, and second on the side of the pin hole nearer the eye. Describe the results and explain with the aid of diagrams.

Let an observer bring his finger between his eye and any convenient object in the field of vision. Let him steadily fixate the finger and draw it nearer and nearer to the eye. He will notice that the remote object which is under observation gradually changes in apparent size. This should be explained.

The part played by sensations of accommodation has been a subject of much investigation. Threads, or, better, a line without width such as can be secured by using the boundary between two surfaces, may be placed at different distances from the observer in the monocular field and measurements made of the ability of the observer to distinguish distances.

Another much-studied problem in monocular space is the problem of the smallest distance between two points or lines which can be seen in different parts of the visual field.

The discussion of the mental processes involved in the recognition of size and distance is very old. One of the most important of the early treatments of the subject is found in Berkeley's "Essay Towards a New Theory of Vision" (1709). A summary by one of the leading modern investigators is to be found in Wundt's "Lectures on Human and Animal Psychology," pp. 170–209.

EXERCISE V

BINOCULAR VISUAL EXPERIENCES

Fusion of the sensations from the two eyes is so highly developed a process that under ordinary circumstances an observer cannot distinguish what parts of his experience come from one eye and what parts come from the other. It will be well, therefore, to begin by calling attention to certain cases where the sensations from the two eyes do not fuse.

Let the observer set up two objects in a straight line extending directly away from the face and let him look with both eyes first at the nearer object and then at the more remote. The object not at the point of fixation will appear double. Let the observer determine in each case what is the relation of the double images to the two eyes. This can be done by closing first one eye and then the other.

Second, let the observer hold before his eyes some solid object extending away from him, and let him examine the object first with the right eye

closed, then with the left. A favorable object for this part of the experiment is a model of a truncated pyramid. After observing the difference between the two images received by the two eyes from such a truncated pyramid, let the observer draw two figures representing the two images.

Third, by means of a mirror stereoscope, let the observer fuse the two figures representing the two images of the truncated pyramid. Let the experimenter then cover successively the right and left half of one of the figures and let the observer describe the results. Superficial observation will not bring out the full result of covering part of the figure. It is, accordingly, well to repeat the observation a number of times.

Fourth, place in the stereoscope two figures which have no lines in common and observe the result.

The report should contain diagrams showing the relations of images and objects when there is no fusion and when the figures are fused in the stereoscope.

The following questions should also be taken up in the report:

Does fusion add to experience anything not contained in the factors fused?

Do the factors fused in the process of binocular fusion lose any of their characteristics?

How far do the sensation factors received from the two eyes impel the subject to fuse the images from the two eyes?

Are there any sensory factors besides the retinal sensations which enter into binocular perception?

Is binocular fusion a sensory process?

The following may be suggested as problems suitable for more extended investigation:

The stereoscope illustrates the fusion of sensations which are presented simultaneously; an apparatus known as the stroboscope illustrates fusion of successive sensations. The succession of images may be given to a single eye and under proper conditions they will fuse into a continuous percept.

Arrange a stereoscope so that the angles at which the images are thrown into the eyes may be readily changed. What is the effect of making changes in the angle at which the images enter the eye?

Arrange a pseudoscope so that the left eye will see more of the right side of an object than the right eye sees.

What other contrivances than the mirror stereoscope can be used for throwing the stereoscopic figures into the two eyes?

Binocular rivalry should be systematically worked out. Also binocular color fusion.

At what distance from the eyes do the optical axes cross when one looks into a stereoscope and fuses the two images?

The stereoscope was devised by Wheatstone in 1838, and his article entitled "On Some Remarkable and Hitherto Unobserved Phenomena of Binocular Vision," which was published in the "Philosophical Transactions" of that year, is the beginning of a large number of scientific studies which have engaged the attention of both physicists and psychologists. The later development of the lens stereoscope by Brewster (see his "The Stereoscope, Its History," etc., London, 1856) gave the stereoscope a form which has made it popular as a means of amusement. For a summary of the articles on the subject consult Sanford, "A Course in Experimental Psychology," pp. 272–301.

SUMMARY OF FIRST FIVE EXERCISES

The foregoing exercises on vision deal with what has been from the very first one of the most productive spheres of experimentation in psychology. Visual experience is so highly developed that it presents most of the typical forms of sensory and perceptual activity; it is so definite that quantitative experiments can easily be devised; it is so much alike in its general character in different individuals that it furnishes common ground for almost all observers. These characteristics of visual experiences justify the use which has been made of them in the introductory exercises in this course. The less highly developed forms of sensory and perceptual experience can be more intelligently examined after the foregoing exercises with vision are completed.

We turn now to a limited number of exercises dealing with other spheres of sensation and perception.

EXERCISE VI

BINAURAL RECOGNITION OF DIRECTION

The spatial arrangement of auditory sensations is a matter of less importance in human experience than is the spatial arrangement of visual and tactual experiences. Auditory space perception is, therefore, relatively less developed than either tactual or visual space, and shows in certain of its phases a marked degree of dependence on other forms of experience. For example, we know the *distance* of an object by means of the sound which it emits only when we are acquainted through earlier visual or tactual experiences, as well as earlier auditory experiences, with the object which gives the sound in question. The recognition of *direction* is more highly developed than the recognition of distance and is consequently less dependent on other experiences. For the recognition of direction the two ears are used in a manner analogous to that in which the two eyes are used in the recognition of depth.

Place two telephones in the same electric circuit so that when the circuit is opened or closed both telephones will sound at the same instant. Place one of the telephones at a fixed distance of 50 centimetres in a horizontal line directly opposite the right ear of an observer whose head is fixed in a rest. In the same horizontal line, but opposite the left ear, place the other telephone successively at the following distances: 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 centimetres. Note that only one sound is experienced from the two telephones. Also make a record of the observer's statements as to the apparent position of the source of this single sound. Repeat the experiment, moving the adjustable telephone back and forth through the whole series of positions three times.

For the remainder of the experiment use a single telephone. Bring this into a position directly behind the middle of the observer's head in the horizontal plane which passes through the ears. Sound it once in this position and then move it slightly to the right or left and sound it again. The observer is to state whether the change in position is perceptible and in which direction it lies. If the direction of movement is correctly given, repeat the process a number of times to make sure

that the correct judgment was not a matter of mere chance. If the observer continues in the successive tests to give a correct judgment, reduce the distance somewhat and thus determine the point at which the observer can no longer recognize the direction of the movement. If the judgment is not correctly given in the first trial, come back to the starting-point and in successive trials gradually increase the distance from the starting-point until the point is determined at which the observer can first recognize correctly the direction of the change in position. Make in irregular order three determinations of the just perceptible distance on the right and three on the left of the middle point. Try similar tests for positions in the same horizontal plane, beginning with the telephone directly opposite one of the ears, and, if time permits, also beginning directly in front of the head, and at oblique positions between the positions above described.

In the report on this exercise reference should be made to the discussion of fusion which was undertaken in connection with the fifth exercise, and a comparison should be instituted between the facts of binocular and binaural perception.

Discuss the questions:

How are the results to be formulated into a general principle of auditory localization?

How far do we consciously discriminate and compare the experiences received through the two ears?

Is objective space different in its various parts in a way corresponding to the variations which we recognize in the field of auditory space?

What is the relation of binaural localization to our recognition of the position of the head through vision, through muscle sensations, or through other means?

What facts of ordinary experience can be cited to show the nature of auditory space perception? Especially, can the experimental results be supplemented so as to show that differences in intensity of the binaural factors are not the only differences of importance?

Further problems may be suggested as follows:

Use instead of telephone clicks some sound which has a complex quality, such as the voice, and compare the results.

Place two sounding tuning-forks of the same quality with their bases in direct contact with vari-

ous parts of the head and describe the apparent position of the sound.

Vary the positions of sound in a vertical or oblique direction, rather than in a horizontal direction, as in the exercise.

Vary slightly the pitch of one of the sounds.

Fasten reflecting boards in front of the ears, or behind one ear only, and study the effects of these on localization.

How far can the ability to localize sounds be improved by practice in a series of quantitatively recorded exercises?

Use three telephones in circuit and determine the principle of fusion.

An excellent summary of the investigations which have been made along the lines of this exercise will be found in Pierce's "Studies in Auditory and Visual Space Perception." See also a paper entitled "Perimetry of the Localization of Sound," by Daniel Starch, published in "The University of Iowa Studies in Psychology, Psychological Review Monograph Supplement, No. 28."

EXERCISE VII

TONAL SENSATIONS

In the last exercise a study was made of the way in which auditory sensations are combined in spatial percepts. In the present exercise auditory sensations will be more fully examined with special reference to the possibility of qualitative discrimination and with reference to the relation of sensations to physical stimuli. This study of auditory sensations will be more productive if the results are constantly compared with the results obtained in analogous experiments with visual sensations.

First, sound in certain cases one tone, and in other cases, without letting the observer know of the change, sound two tones of equal intensity at the same time in the combinations indicated below. Require the observer to give one of the following judgments: either, (1) certainly two tones, (2) probably two, (3) altogether doubtful, (4) probably one, (5) certainly one. Repeat each test in irregular order five times and tabulate the

answers. The combinations to be used are as follows: *cd*, *ce*, *cf*, *cg*, *ca*, *cb*, *cc'*, *cd'*, *fd*, *fe*, *fg*, *fa*, *fb*. An inspection of the table of answers will make clear the difference between the combinations which tend to fuse and those which do not. A table should be prepared showing the ease or difficulty of fusion in the different combinations.

Second, try three of the above combinations which are easily recognized as made up of two tones, and three of the combinations which are not so recognized, sounding one of the two tones with greater intensity than the other, and make a similar record of the answers.

Third, sound the tone *c* and immediately after sound with equal intensity a tone slightly higher or lower than *c*. If the observer does not recognize the difference, increase the difference until he does. If he recognizes the difference, gradually reduce it until it is no longer perceptible. Do the same for some other tone.

Fourth, sound certain tones in succession so as to give the intervals *c-e*, *c-g*, and *c-b*. In each case, after sounding the standard interval, sound two tones which are either farther apart than those in the standard interval or nearer to each other. If the subject recognizes the difference between the

two intervals, gradually bring the second interval nearer to the standard until the point is reached at which the two intervals seem alike to the observer. If the first difference between the intervals to be compared is not recognized, increase it until it is.

In the report discuss the difference between mixed tones and mixed colors, without referring to any facts outside of the results of the laboratory exercises.

What principles of tonal combination can be formulated on the basis of the results of this exercise?

Account in terms of physiology for the facts in your report, distinguishing sharply between hypothesis and known fact.

What is the relation of tonal experience to physical fact?

Why does change in intensity modify tonal discriminations?

Does the process of discrimination of tones differ from the hearing of tones?

Is there anything besides discrimination of tones involved in the recognition of intervals?

Can any relation be recognized through introspection between tonal experiences and movements of the organs of articulation?

Other investigations of auditory sensations which should be undertaken may be suggested as follows:

Sound together two tones of the same octave, as, for example, *c* and *e* and note in the complex the tone (called difference tone) which is lower than *c*. This exercise can be made an exercise in definite quantitative determination by requiring not merely the observation of the difference tone but its reproduction, as, for example, on an adjustable tuning-fork.

Sound together two tones which are slightly different, and count the beats. The number of beats shows the difference between the number of vibrations of the two tones.

Produce a variety of noises by striking objects about the room, and note the differences in pitch which are exhibited by these objects.

Find the highest pitch that can be heard. Find the lowest pitch that can be heard.

The most complete investigation of all the facts dealt with in this exercise is in a German treatise by Stumpf, entitled "Tonpsychologie." A very good summary of the facts is given by Stout in his "Manual of Psychology," pp. 171–81.

EXERCISE VIII

CUTANEOUS SENSATIONS

This exercise and the next will be devoted to the investigation of experiences which result from stimulation of the sense organs of the skin. The skin is supplied with a great number of sensory nerves and is the source of a number of different kinds of sensations. This exercise will consist in a thorough examination of a small area of the skin. The next exercise will deal with the perceptual processes which arise from skin sensations.

Select a region about two centimetres square on the volar surface of the forearm, mark it off into square millimetres, and explore it minutely for the ability of its different points to respond to different kinds of stimulation. On a paper also marked off in square millimetres make a map of the results of this exploration. The most characteristic results will be found by beginning with cold. Let the experimenter pass a cold metallic point systematically over all parts of the marked area and note

on the map the spots described by the observer as most sensitive to cold. Similarly with a warm metallic rod let the warm spots be found. To determine various degrees of sensitivity to pressure, let bristles of various sizes be used. By means of a very fine bristle the points most sensitive to pressure can be located. By taking coarser bristles, other less sensitive points can be added to those found with the fine bristle. The same kind of exploration for pain points is possible, but may be omitted from this exercise.

The report should take up the following questions:

Show the relation between this experiment and that described in the second exercise of this course. Also, show in this case the advantage to the individual of a differentiated organ of sense.

Once more consider the relation of experience to the physical facts.

Why does ordinary experience of cold, heat, and pressure fail to reveal the several variations of sensitivity of different points of the skin?

The investigations introduced by this exercise may be extended as follows:

Heat and cold to a very great degree, pressure to a less degree, are matters of change in stimulation rather than absolute stimulation. Place the two hands for a few moments, one in a dish of cold water, the other in a dish of warm water, and then put both into the same dish of lukewarm water. Touch with the two hands a piece of metal and a piece of wood which have been standing in the same room long enough to take on the temperature of the room. Increase at varying rates the pressure or temperature stimulation applied to the skin of an observer and measure the amount of change necessary to produce a just noticeable difference.

The impression made by cutaneous stimulations is said to differ in degree according to the area stimulated.

The surface of the tongue has, in addition to the organs of touch, special organs of taste. The organs of taste are differentiated from each other as they are differentiated from touch, and as the touch organs are differentiated from each other. Show how the experimental investigation of the surface of the tongue should proceed.

Are the points on any given area of the skin stable; that is, can the same points be demonstrated day after day?

What differences are exhibited by different parts of the body of the same observer with reference to the distribution of different kinds of sensation points on the skin?

There has been much investigation in recent years of the structure of the skin as an organ of sense. There are many different structures present in different parts of the skin, but it has not been possible to discover anatomical facts to parallel the various different facts of experience investigated in this exercise. A very good summary of the facts is to be found in Wundt's "Outlines of Psychology," pp. 51–54.

Investigations of taste and smell have also been made. These senses are of so slight importance in human mental life that these investigations have more physiological importance than psychological. Summaries of the facts of importance in these spheres may be found in Wundt's "Outlines of Psychology," pp. 59–62.

EXERCISE IX

TACTUAL SPACE PERCEPTION

Space perception through touch was one of the first psychological problems to be investigated experimentally. In 1846 E. H. Weber published in Wagner's "Handwörterbuch der Physiologie," an article entitled "Tastsinn und Gemeingefühle," in which he reported a series of experimental and incidental observations on tactual sensations and organic sensations. Weber was a physiologist and his interests were primarily physiological. He took up his problem, not so much with a view to studying experience, as with a view to studying the organs of sense. His results were, however, of such importance in explaining experience that the article referred to has been regarded as one of the classics of experimental psychology. That Weber was dealing with a fact much larger than the structure and behavior of the organs of touch in the skin has been fully shown by investigations since his day.

The first two parts of this exercise utilize Weber's second and first methods respectively. The third is added to give greater range to the facts, and it will also serve to show that the processes investigated in the first two parts of the exercise are not purely physiological.

First, let the observer sit, with his eyes closed or covered and his hand and arm supported in a comfortable position, before the experimenter. Let the experimenter touch for a brief interval a point on the lower arm or hand, being careful to mark the spot touched. Require the observer, with eyes still closed, to place a pointer on the spot touched. Mark on a map of the region the point touched and the point indicated by the observer. Do the same with four other spots, distributed as far from each other as convenient, and then in irregular order come back to each of the spots until each has been tested five times. This is Weber's second method.

Second, apply simultaneously two hard-rubber points to the skin of the volar surface of the forearm of a blindfolded observer. Let the distance between the two points be at first one centimetre or less, and determine, by gradually increasing this

distance between the points, at what distance the two points are regularly distinguished as two. Make all the applications of the points in the same direction along the skin, but do not allow the observer to know beforehand what the direction is to be. The observer is called upon during the experiment to recognize the direction as well as the separateness of the two points. In order that the statement of the subject that he recognizes two points may be fully tested, let the experimenter from time to time use a single point instead of two. Make three determinations of the distance on the lower arm at which the two points are distinguished, and like determinations on the ball of the thumb and the second joint of the middle finger. This is Weber's first method.

Third, apply to the skin of the observer continuous lines instead of two points separated by an open space. Determine, as in the second part of the exercise, the length of the line which is distinguished from a single point and the length at which the direction of the line is recognized.

In the report the following questions should be discussed:

What is involved in spatial discrimination more

than was involved in the qualitative discrimination investigated in the last exercise?

What is the difference between discriminating points and recognizing their relative positions?

Compare the results of the various types of experiments in this exercise and explain any differences in the results.

Further studies of tactual space perception may be made as follows:

Make tests by Weber's first method, first in a transverse direction across the arm, and then in a longitudinal direction along the arm.

Make tests on symmetrically opposite positions on the two arms.

What is the effect of practice on the discrimination of lines and separate points?

Does practice with one part of the skin improve the ability to discriminate in other parts?

The relation of touch to vision can be tested by making a preliminary series of experiments, preferably by Weber's second method, and then introducing a practice series in which the observer is given an opportunity to improve his visual knowledge of the region examined, and finally testing again by Weber's second method.

Test the ability to recognize extension and direction with a point which is moved over the skin at different rates.

General ability to recognize positions of the whole body is doubtless in part a matter of skin sensations, but it also involves other factors, some of them related to vision and some to sensations from the semicircular canals. For experiments with the latter, determine the accuracy of localization when the eyes are covered and the head is turned in various directions or the whole body is brought into unusual positions.

In addition to Weber's article referred to above, a large number of investigations have been made on this subject. The most complete summary is to be found in a German work by Henri, entitled "Ueber d. Raumwahrnehmungen des Tastsinnes," 1895. A brief English summary is to be found in Sanford's "Course in Experimental Psychology," p. 4; a more complete summary is to be found in Stout's "Manual of Psychology," pp. 342–62.

EXERCISE X

SENSATION INTENSITIES

The early experimenters in psychology devoted much time and energy to the investigation of sensation intensities. Weber, to whom reference was made in the last exercise, reported in a paper earlier than that on "Tastsinn und Gemeingefühle," certain experiments on the intensities of pressures. These showed that the sensations of pressure do not increase in strength in direct proportion to the intensity of the exciting external stimulation. Fechner afterward made the matter a subject of elaborate experimental investigation and reported his results in his book "Elemente der Psychophysik" (1860). In this book Fechner took up the question of the relation between mental life and its external conditions, and the methods of investigating this relation in so far as it appears in sensation intensities. He worked out certain mathematical formulas for the treatment of his experimental results and made a vigorous effort to put this part of psychology on a basis equal in

mathematical exactness to physics. After Fechner came a number of investigators, including many of the earlier workers in the first psychological laboratory, all devoting their efforts to the elaboration of Weber's and Fechner's results. Many of these later investigators were interested primarily in the development of mathematically exact methods of treating mental phenomena; some were interested in the study of the relation between mental experiences and their physical conditions.

In this exercise two of the fundamental psychophysical methods will be illustrated and enough of the typical facts will be brought out to demonstrate the general law known as Weber's Law.

First prepare two pairs of weights, one pair consisting of weights of 100 grammes and 103 grammes, the other pair consisting of weights of 400 grammes and 412 grammes. These weights should be so constructed that when they are lifted by the observer they can each be taken up in exactly the same way. Let the observer be seated with closed eyes and with his arm supported in such a position that he can easily lift the weights as they are presented to him by the experimenter. The experimenter should take one pair of weights

and should present them one after the other to the observer, who should lift them in succession. The order in which the weights are presented should be wholly unknown to the observer, but should be so arranged by the experimenter that, the pair being presented one hundred times in all, in fifty cases the heavier weight comes first, and in an equal number of cases the lighter weight comes first. The observer lifts the weights as presented and renders a judgment as to the relation of the second weight to the first. Thus, he may say that the second is heavier or lighter. Some forms of the method allow the judgment equal, and some forms of the method take a record of the degree of certainty of each judgment. In this exercise let the subject be required to give one of the two answers, heavier and lighter. When the one hundred answers have been given, they should be tabulated as right or wrong. Taking this simple case, in which only two answers are allowed, it is obvious that if in any particular instance the observer has no basis in his experience for the judgments rendered, his correctness or incorrectness will be a mere matter of chance, and on the well-established mathematical principle of probability, he should have about fifty per cent right answers

and fifty per cent wrong. If he has more than fifty per cent wrong answers, some constant influence must have been at work leading to biased judgments. If more than fifty per cent of the answers are correct, there must be a constant influence drawing in the positive direction, and this influence may safely be sought in the fact that the difference in the experiences produced by the two weights is approaching the point of recognition. If the difference is great enough to be clearly recognized in every case, it will obviously be much greater than is required for the purposes of this experiment, where it is desirable to determine what difference is necessary to produce recognition under average conditions. By a well-known mathematical principle, it can be shown that the case in which seventy-five per cent of the answers are correct is the case in which the recognition may be fairly treated as occurring under average conditions.

The following table, prepared by Fullerton and Cattell, may be used to calculate the probable difference between two weights or other stimuli which is necessary to produce seventy-five per cent correct judgments, if that difference is known, which will produce any percentage more than fifty of right judgments. Thus, if the judgments are right

in 68 cases and wrong in 32, when weights of 100 and 103 grammes are compared 100 times, the percentage of right cases will obviously be 68. Referring to the table, we find that this indicates that the difference 3, which existed between the two weights, is .69 of the difference which may be expected to secure seventy-five per cent correct judgments. The calculation is as follows:

$$1.00 = 4.3 \text{ gm. when } .69 = 3 \text{ gm.}$$

Per cent right judgments.	Known difference divided by difference sought.	Per cent right judgments.	Known difference divided by difference sought.	Per cent right judgments.	Known difference divided by difference sought.	Per cent right judgments.	Known difference divided by difference sought.	Per cent right judgments.	Known difference divided by difference sought.
50	.00	60	.38	70	.78	80	1.25	90	1.90
51	.04	61	.41	71	.82	81	1.30	91	1.99
52	.07	62	.45	72	.86	82	1.36	92	2.08
53	.11	63	.49	73	.91	83	1.41	93	2.19
54	.15	64	.53	74	.95	84	1.47	94	2.31
55	.19	65	.57	75	1.00	85	1.54	95	2.44
56	.22	66	.61	76	1.05	86	1.60	96	2.60
57	.26	67	.65	77	1.10	87	1.67	97	2.79
58	.30	68	.69	78	1.14	88	1.74	98	3.05
59	.34	69	.74	79	1.20	89	1.82	99	3.45

More elaborate methods of calculation are necessary if the observer is allowed to give not merely the answers lighter or heavier, but also the answer

equal. In general, it may be said that this third answer carries one over into the sphere of elaborate mathematical formulas. These elaborate formulas have led to much discussion in psychology, but to few, if any, important conclusions. They may safely be omitted from a general course.

After trying the series with 100 grammes and 103 grammes, try a second series with 400 grammes and 412 grammes.

The method here employed is known as the method of right and wrong answers, and the problem to which the method is applied is the problem of determining the probable threshold of difference.

Second, gradually reduce the intensity of a sound stimulation until the observer can no longer hear it. Then beginning with a stimulation too weak to be heard, increase its intensity until the observer can just hear it. The method here employed is a very common method and is called the method of minimal changes. The point at which the sound becomes just audible is called the initial threshold.

Third, use a photometer, and beginning with two lights of equal intensity find the just observable difference when one light is gradually reduced

or increased in intensity. After the first determination is completed, increase the general illumination in the room and make a like determination of the just noticeable difference. This is an application of the method described in the second section of this exercise.

In the report on these experiments discuss the difficulties and advantages of the several methods.

Show why the psychophysical methods deal always with cases of equality, just noticeable difference and just perceivable impressions, rather than with impressions which differ from each other in clearly recognizable degrees.

Is the psychical experience measured by these methods, or is the measurement confined to the objective stimuli?

What is the explanation of the lack of direct correspondence between stimulus and impression?

In connection with the discussion of sensation intensities, discuss the distinction between vividness and intensity, and the distinction between relative importance and intensity.

Further methods may be devised.

Devise a method for comparing the likeness or

unlikeness of differences between two pairs of sensations and thus testing Weber's Law.

With the methods at hand every sphere of sensation may be examined, and even certain simple forms of perception may be experimentally measured. The following illustration suggests certain problems which have been taken up since Fechner's time.

Find the least perceptible difference for sounds.

Find the least perceptible pressure (see Exercise VIII on pressure spots).

Find the least perceptible differences in lines.

The relative value of these "psychophysical" investigations is differently estimated by different psychologists. A recent elaborate treatment of the whole field is to be found in Titchener's "Experimental Psychology, Instructors Manual, Quantitative." This work can hardly be described as typical of the current psychological estimate of the importance of psychophysics to general psychology. A summary which places the matter in much better perspective is to be found in Stout's "Manual of Psychology," pp. 199–209.

SUMMARY OF FIRST TEN EXERCISES

Up to this point the exercises of this course have dealt with processes of sensation and perception. Little or nothing has been said regarding activity and its relation to experience. A number of exercises will now be devoted to the study of activity. The methods of such a study differ radically from the methods employed in the foregoing experiments, and the first exercise of this part of the course will be devoted to the cultivation of ability to manipulate the apparatus and methods employed in recording and analyzing movements.

EXERCISE XI

APPARATUS AND METHODS FOR RECORDING MOVEMENTS

The first requirement, if one is to make a study of activity, is a delicate means of recording the various movements of the body. A record carries one much farther than mere observation, even where the movement is gross enough to be easily seen, for the details of a movement ordinarily pass before one too rapidly to be fully noticed. In a record the details can be studied at leisure. Furthermore, even when the movement is gross, records make comparisons with other simultaneous movements easily possible, where it would be very distracting to try to observe two movements at the same time. When the movement is so slight or so inaccessible as to escape ordinary observation, it is clearly necessary to devise some method of making a record.

The essentials for recording a movement are, first, some device for receiving and transmitting the

movement to a recording surface, and, second, a suitable surface on which to make the record.

A typical recorder, which has a great variety of uses, is the tambour. Set up a tambour and report its form and mode of operation by means of a diagram. Discuss its advantages and limitations in the report.

A kymograph furnishes the most convenient surface on which to make the record. Make a record with the kymograph. Explain the essential parts of this apparatus and show how it operates. Enclose the record with your report.

A standard time-line is required in many cases in order to determine the rate of the movement under investigation. Explain a method of securing a standard time-line.

Suggest in the report some records which could be made by means of the combination of apparatus with which this exercise deals.

EXERCISE XII

CHANGES IN CIRCULATION ACCOMPANYING CHANGES IN CONSCIOUSNESS

There are a large number of internal bodily movements not open to ordinary observation, which show changes whenever there are changes in conscious experience. The circulatory changes, which can be studied by taking a record from the pulse in some artery near the surface of the body, are typical of these internal movements. This exercise will be devoted primarily to the demonstration of the fact that there are circulatory changes which accompany changes in consciousness. In the second place, an effort should be made to discover, if possible, any regularity in the character of these changes. The discovery of regularity is less easy than the mere demonstration of change and may require more elaborate investigation than is possible in a single exercise.

Adjust a sphygmograph on an artery and after the reactor settles into a quiet condition, which

usually can best be brought about by requiring him to close the eyes, take a record for about two minutes. After securing this so-called normal record, require the reactor to multiply two numbers and let the experimenter mark on the record the period during which the reactor is making the mental effort. Let the reactor again relapse into a quiet condition and secure a second normal curve. Again arouse in him some new form of experience. The reactor may be given a sweet or bitter taste, a loud noise, a skin stimulation; or various forms of mental activity may be required of him. Before and after each change in experience secure a normal record for at least two minutes.

The results of this experiment should be presented in the form of a statement of the number of pulse beats for an interval before each excitation, the number during an equal period of excitation, and finally the number during a third equal period following the relapse into a quiet condition. Furthermore, any change in the intensity and form of the pulse should be noted.

In the report there should be a discussion of the relation of bodily movements to nervous processes.

Show, also, to what extent the nervous processes which result in movements are related to the nervous processes which condition consciousness.

Are we conscious, in any sense of the word, of our circulatory changes?

Why are the circulatory movements called involuntary?

How far do the facts demonstrated in this exercise justify us in assuming that all conscious changes are accompanied by bodily movements?

If any regularity was discovered in the relation between experience and the accompanying movement, explain this.

What is the biological importance of the relation between movement and consciousness?

Further investigation of changes in involuntary movements may be undertaken as follows:

Circulatory changes may be investigated by means of the plethysmograph, an apparatus which measures the volume of a limb of the body.

A measure of the volume of the circulation may be made by means of the recoil table.

Changes in the rate and intensity of respiration may be measured.

The size of the pupil of the eye varies with

changes in attention and feeling. More careful measurement of these variations is desirable.

Changes in the movements of the digestive organs have been investigated by feeding animals a quantity of insoluble substance and observing the movements of this insoluble mass by means of the X-rays.

The importance of the relation under investigation in this exercise was first brought out with clearness in the discussions of James and Lange. Consult James's "Principles of Psychology," vol. ii, pp. 442–85. For experiments see also Angell and Thompson, "Psychological Review," vol. vi, 1899, p. 32.

EXERCISE XIII

CHANGES IN MUSCULAR TENSION OF THE VOLUNTARY MUSCLES

Marked changes in the tension of the voluntary muscles may easily escape attention. Experimental methods serve to bring out these changes in great number and variety.

First, attach the finger of a reactor to a tambour and require him to hold it as still as possible while thinking intently of the finger. Then let him think intently of other things, as, for example, of some object in the room or on the street, or let him count or read. Give him pleasant or unpleasant odors or tastes.

Second, attach the head to a tambour and try a similar series of experiments.

Third, lay the hand of the reactor on a planchette and let him think intently of journeying across the continent or around the world, or let him count the strokes of a pendulum or watch the movements of some other person. Also, try the

effects of pleasant and unpleasant tastes and odors.

The experiments required in this exercise are often unsatisfactory in their results because the reactor is distracted by the conditions under which his movement is recorded. For example, in the third part of the experiment, there will be a tendency to divide attention between the hand on the planchette and the train of ideas. The reactor can overcome this difficulty in part by exerting himself to concentrate attention on the train of ideas. The experiment should be tried with deliberation, and the same experience should be repeated several times. In this way the reactor will have time to become familiar with the conditions under which he is working and will be less and less distracted from the experience to which he should give himself up.

In the report on this exercise, show the relation between such movements as are here under investigation and the movements discovered in the last exercise.

Is there any hard-and-fast line between these "changes in tension" and ordinary voluntary contractions of the muscles?

What facts of ordinary experience can be cited to extend the results obtained in this exercise?

Is the presence of these involuntary changes in tension wholly without effect on consciousness?

The exercise could be extended to other forms of movement.

How could the changes in tension of the vocal organs be tested?

How could changes in the tension of the muscles of the tongue be measured?

Measure the maximum strength of the hand in a quiet room where it is dark. Then increase the auditory and visual stimulation and measure again the strength of the hand.

A full report of investigations on involuntary hand movements is given in Jastrow's "Fact and Fable in Psychology," pp. 307–36.

A discussion of the relation of movement to consciousness, together with a brief summary of some of the important recent papers on this subject, will be found in the "Yale Psychological Studies," New Series, vol. i, pp. 199–226.

EXERCISE XIV

MUSCULAR COÖRDINATION

The last two exercises have demonstrated the great variety of movements which accompany conscious processes. The next step in the experimental study of activity is to discover the characteristics of various kinds of movement and the influences which affect these characteristics. One of the most obvious differences between movements, and one which is closely related to conscious experience, is the difference between a well-organized movement and a movement which is not well organized. The present exercise will deal with these differences in organization or differences between coördinated and incoördinated movements.

Record the movements of the fingers of the right hand when they are moved downward, as in playing a piano, with the greatest possible rapidity, in the following order, which to most persons seems to be the natural order: little finger, third finger, middle finger, and index finger. Follow this with a

record of similar movements in the reverse order. The records should be compared with special reference to the rate and regularity of the two series of movements.

Second, let a series of straight lines of convenient length be drawn as rapidly as possible with the right hand, under such conditions that a full record will be secured of the rate and regularity of the movements involved. Under like conditions, draw a series of similar lines with the left hand. The right-hand series and the left-hand series should be carefully compared with reference to both speed and regularity.

The results of these experiments should be reported in definite quantitative form. This can be done by comparing the rate of the finger movements in the first part of the exercise with a standard time-line. Measure in ten or twenty successive cases the average duration of pressure of the little finger and the mean variations for the same. In like manner, measure the interval between the little finger and the third finger, the duration of pressure of the third finger, and so on. The quantitative results for movement in the easy and natural order should be compared with like results for the second or less easy type of movement.

In the case of the lines, measure the rate of movement for typical portions of each line.

Consider in the report the following questions:

What are the nervous conditions involved in coördinated and incoördinated movements?

How far are these movements sources of sensations of movement?

Are there any relations between these movements and consciousness, other than that which is established through their contribution of sensations of movement to experience?

How far can we control an incoördinated movement, and what is necessary to the development of complete control?

How far is conscious volition in control of a coördinated movement?

Considering coördinated movement as a distinct advantage to the individual, how far does a consideration of animal and human behavior justify us in assigning to consciousness a part in the development of coördination?

There is unlimited opportunity to contrast developed and undeveloped movements. The great defect of ordinary observations is that they are not exact and quantitative. The scientific investi-

gation of coördination would add much to the definiteness of many forms of education which aim to develop coördination. The first step in this scientific study is to establish fully the distinctive characteristics of coördinated and incoördinated action.

Scientific studies of this sort may be suggested as follows:

A variety of right-handed and left-handed performances may be measured, such, for example, as tapping, writing, and drawing.

Other untrained parts of the body, such as the feet, can be contrasted with the hands.

A complete record of the ungraceful movements which are exhibited in the early stages of acquiring some complex movement, such, for example, as swinging Indian clubs or maintaining one's balance in a new situation, would throw much light on the development of coördination, and would, at the same time, give excellent illustrations of the difference between trained and untrained movement.

A good example of recent efforts to study this problem will be found in an article by Swift in the "American Journal of Psychology," vol. xiv (1903), pp. 201–51.

EXERCISE XV

UNNOTICED VARIATIONS IN SIMPLE COÖRDINATED MOVEMENTS

Successive executions of a coördinated movement are not uniform. Every variation in the mental attitude of the reactor is reflected in the character of his movement. This is, of course, obvious in those cases in which the change in mental attitude is deliberately assumed with a view to influencing action as in ordinary voluntary modification of one's movements. But even where the reactor aims to repeat the movement in the same way in a number of successive cases, and is not conscious of any differences, marked effects of different degrees of expectation and preparation always show themselves. In order to demonstrate these changes a simple type of movement may be executed a number of times under uniform conditions, and the characteristics of each movement determined quantitatively. The simplest method of demonstrating variation in movements is to measure their duration. This method was very extensively employed

in the early period of experimentation in psychology, and is of value for many purposes when properly carried out. The tendency in recent experimentation has been to go much further than merely to measure duration. The most productive method is to secure, at the same time that the duration is measured, a graphic record of the form of the movement.

Let the reactor prepare to raise his hand as quickly as possible and in a manner as nearly uniform as possible in response to a stipulated sound. About two seconds before the sound which is the signal for the reaction is given, the reactor should be warned in order that his attention may be at its maximum. Proper mechanical appliances should be arranged so as to record (*a*) the way in which the movement is made and (*b*) the promptness with which it is commenced. Each time the reaction is executed the reactor should note as fully as possible his mental processes and the results should be studied with a view to relating the introspected facts with the facts of movement. A series of at least ten tests should be made with each reactor. Variations in the period of preparation and in the direction of the reactor's attention may be

introduced. Under the last-mentioned class of variations, let the reactor in one group of cases concentrate his attention as closely as possible on his hand, while in another group he concentrates attention on the signal to react.

In the report on this exercise, describe, with the aid of diagrams, the various modifications which appear in the form of the reaction movement.

Consider the physiological conditions which explain these variations in form of movement. Can the physiological conditions thus referred to be in any way connected with the observed changes in consciousness?

Again, consider the general question of how far the reactor is conscious of his movement, and the question of how movement may be related to consciousness by other avenues than through sensations of movement.

The investigation may be extended by taking up one or more of the following problems:

Try simple reactions for visual and tactile stimulations.

Let the reactor draw lines of various lengths at a given signal, arranging the apparatus so as to

measure the rate of the movement and the promptness with which it is taken up after the signal.

Let the signal given the reactor be a signal to stop a movement in which he is engaged, rather than to begin a movement.

Take graphic records with the left hand in all these cases.

A summary of results, secured by comparing the movements of a large number of reactors, will be found in the "Yale Psychological Studies," New Series, vol. i, pp. 141–84. For an exhaustive treatment of the methods of time measurement, consult Titchener's "Experimental Psychology, Instructor's Manual, Quantitative."

EXERCISE XVI

VOLUNTARY MODIFICATIONS IN MOVEMENT

Instead of attempting to repeat a simple movement with the greatest possible uniformity, let the reactor prepare to react in a special way according to the stimulus. Thus, for example, if the stimulus is a visual sensation of green, let him react with the right hand. If the stimulus is blue, let him react with the left hand. The movement will in this case depend upon a conscious effort to fit reaction to stimulus. Forms of impression other than the visual sensation mentioned may be used in like fashion.

With the same means as in the last exercise, prepare to record the form and rate of a reactor's movements, it being arranged that the movements shall comply with directions similar to the following:

First, when the reactor hears a sound on his right, he shall refrain from reacting altogether. When he hears a sound on his left, he shall react as

in the simple reaction experiments. This experiment is usually referred to as an experiment in discrimination reactions. Another form of the same experiment is to require the reactor to respond when he sees a red color exposed and to refrain from all reactions when he sees green.

Second, let the reactor lift his right hand when he sees red and his left hand when he sees green. This is known as a choice reaction. Or try the same experiment for sounds variously located.

Third, measure the time involved in articulation responses without aiming to get a graphic record of the mode of the articulation movement. Measure the time required to recognize and read a single word. Also measure the time required to articulate a word suggested by association with the word shown.

In the report take up the following questions:

What physiological processes are present in a complex reaction more than in a simple reaction?

What conscious processes involved in complex reactions are not present in simple reactions?

Can the two groups of facts referred to in the above questions be related to each other?

Distinguish also between the various forms of

complex reaction, both as to physiological processes and conscious processes.

Does the appearance of a simple hand movement as the reaction in these complex reactions justify the statement that the activity is a simple one?

Are there any indications, in the forms of movement recorded, of the more elaborate preparatory processes involved in the complex reactions?

In general what is the relation of complex mental processes to bodily activity?

Further suggestions of possible applications of complex reaction methods are as follows:

Discrimination reactions may be arranged to measure the difficulty or ease of reacting discriminatingly to shades of color closely related and shades that are very different. In like manner, the time of reaction differs for different intensities of sound or light.

Choice reactions may be arranged to involve any number of different movements as, for example, movements with five or more different fingers.

Special variations of the association experiments may be devised. Require the reactor to name a part of the object designated by the signal word,

or require him to name the group to which the designated object belongs.

A very simple method of experimenting with discrimination reactions is as follows: Let the reactor be required to strike out all the letter a's which occur in a page of print. This involves a recognition or discrimination of the letter and a movement to mark it out. The time required to cover the whole page is taken with an ordinary stop-watch, and the average time consumed in individual discrimination reactions is ascertained by dividing the total time by the number of letters marked out. Instead of using chance distribution of letters, as in a page of print, printed forms may be made up especially designed for the experiment.

The references given under the last exercise will serve to introduce the student to the literature of reaction experiments. A good brief summary of the results of such experiments is to be found in Wundt's "Outlines of Psychology," pp. 215–22.

EXERCISE XVII

ANALYSIS OF VOLUNTARY COÖRDINATIONS

One of the most highly developed coördinations common to all educated individuals is the writing coördination. This coördination can be studied by time measurements, and it can also be analyzed directly into its elements. Other simpler forms of voluntary movement can also be analyzed so as to show the combination of movements involved, and also the changes in this combination which arise when the reactor is made to attend during the movement to certain varying demands which must be met by an immediate voluntary readjustment.

First, take a record of the natural writing under conditions which will make possible an accurate time measurement of all the parts of the writing. Then modify the conditions by requiring the reactor to write between guiding lines, care being taken to make the guiding lines a little farther apart, or a little nearer, than the reactor would naturally choose.

Second, fasten a recorder to the hand in such a way as to secure a record of the part played by the hand during ordinary writing. Take another record of the same kind to show what part the hand plays when the reactor is required to write between lines.

Third, take a graphic record of the hand movement made in striking at a moving point. Arrange so that there shall be irregularities in the movement of the point, these irregularities occurring sometimes before the movement begins and sometimes during the movement. Compare the types of movement and experience involved in these various cases.

In the report give diagrams to illustrate each group of results. Also explain how the guiding lines in parts one and two, and the perception of movement in part three, modify experience and movement. Treat in this discussion the physiological processes involved.

Are the changes in movement reported to consciousness in the form of incoming sensations?

Consider the relation of the facts treated in this exercise to the facts of habit. Illustrate the way in which a habit is sometimes modified by new environment.

The analysis of writing movements may be extended so as to record the behavior of the different parts of the arm, also the pressure against the pen exerted at different moments by each of the fingers which hold the pen. Here, also, the different forms and conditions of writing may be examined. What is the result, for example, of changing from a pen to a pencil?

Arrange a balance and measure the amount of downward pressure exerted upon the writing surface during writing under various conditions.

The movement made in striking a moving point would furnish a very good basis for the comparison of human and animal forms of action. It would also be a very good means of studying the modifications of behavior in animals which have been deprived of certain of their natural organs of sensation, as, for example, in animals or human beings with only one normal eye.

A general study of movements of a very simple sort is reported by Woodworth in the "Psychological Review, Monograph Supplement, No. 13." A summary of results of experiments on writing is given in the author's "Genetic Psychology for Teachers," pp. 170–79.

EXERCISE XVIII

EFFECTS OF PRACTICE—(*A*) IMPRESSION FACTORS

No experiment, either in perception or expression, can be tried without involving to some extent effects of practice. If the results obtained in the early part of an experimental series are compared with those obtained in the latter parts of the series, the differences between the two groups of results may usually be accounted for in very large part as the results of practice. What is meant in any particular case by the term practice depends on the conditions under which the series of experiments is carried out. For example, if the experiment is one dealing with tonal recognition, "practice" will refer to improvement of the individual in the discrimination of tones. Practice in choice reactions will show itself in speed and precision of reaction.

It will be the purpose of the next two exercises to undertake an experimental analysis of certain typical cases of practice, and to study, in this way,

the changes produced by development in the relations between various factors of experience. Such an analysis will show in certain cases that the chief improvement has been in apprehending more fully and organizing more completely the sensory factors. In other cases it will be found that it is chiefly the relation between the motor factors which is modified through practice. In a third type of cases, the sensory factors and the motor coördinations are not especially modified, but the relation between sensations and motor processes is changed during the practice series.

Such exercises as these will serve to reënforce the teachings of the foregoing exercises, that experience is dependent on both motor and sensory conditions. To be sure, the time available for such exercises as can be taken up in this course makes it impossible to follow the processes of development under discussion very far. For more complete studies, reference may be made to the following typical researches:

Bryan and Harter, "Psychological Review," vol. vi (1899), p. 346.

Swift, "American Journal of Psychology," vol. xiv (1903), p. 201.

Cameron and Steele, "Yale Psychological Studies," New Series, vol. i, p. 83.

Of the two exercises here outlined, the first will not require any change in the relation between the factors of the movement involved, but will deal chiefly with the relation of sensory factors to practice.

Let a reactor look for ten seconds at a simple drawing which has been made of straight and curved lines combined in simple relations that can be readily measured. After looking at the figure, let him close his eyes and try to make an exact reproduction of the figure set as a model. Let him also describe his experience as fully as possible.

In this case he has been deprived of (*a*) opportunity to form a complete percept of the pattern; (*b*) the visual impression of the pattern during the drawing; and (*c*) the visual image of his own reproduction. Take ten successive drawings from the same figure. These will gradually correct the limitation (*a*), and at the same time show its importance.

Second, using a different combination of straight and curved lines which, however, has the same number of lines and the same general character as that used above, cover the reactor's hand so that he cannot see his own drawing, but allow

him to see the pattern during his reproduction. This will supply the guidance referred to in (*b*) above. Again, let the reactor describe as fully as possible his experience. Make ten such drawings from the same figure.

Third, with a third combination of lines directly comparable to those used before, let the reactor draw while looking at his reproduction, but not at the pattern. Repeat ten times with the same figure.

The drawings produced by the reactor should be carefully measured to find out in detail the errors in form, length, and direction of each of the lines in the reproductions. These errors should be expressed numerically and tabulated, and curves should be plotted to show changes in successive drawings of each group.

In the report compare the three groups of results with reference to the following matters:

1. Extent of average error in reproduction.
2. Improvement in successive reproductions.
3. Relation of subjective certainty to accuracy.
4. Relative values of factors indicated in *a*, *b*, and *c*.

Also consider certain ordinary acts other than

drawing, and point out the sensory controls which are in each case essential to the highest success.

Is a person explicitly conscious of the sensory control which he is exercising over his ordinary movements?

Is the visual impression which might be used for control always employed to the fullest possible extent, as, for example, in ordinary writing?

Other experiments emphasizing sensory control are as follows:

Measure the accuracy with which one can hold a tone of his own selection. Measure the accuracy with which he can imitate a tone sounded for a short interval and for longer intervals. Extend the standard tone into the period of the reactor's response and measure the accuracy of the imitation.

Let the reactor try to hit a target and measure the improvement through practice: (*a*) when the reactor does not know anything about the results; (*b*) when the reactor is told the results, but does not see them; and (*c*) when the reactor sees the results.

In such drawing experiments as those required in this exercise, let some one else look at the reproductions and give the reactor the benefit of a verbal

criticism of the reproduction. Measure the effects of this indirect social control. Again, let the reactor use both hands as the blind do. A very simple method of trying this two-handed experiment is to use as the drawing point a sharp steel point. During the reproduction of the figure, let the reactor press this point well down into soft paper. The line which it leaves can easily be felt by the finger of the hand not engaged in drawing.

A sensory control of writing which is usually overlooked is that which comes from sensations of pressure in the fingers which hold the pen. Use a stylus so arranged that the reactor cannot feel resistance, and let him now try to write or draw without either visual or tactual sensations.

The references mentioned in the introduction to this exercise will serve to suggest the importance of studies in development. In general, it may be said that this phase of experimental psychology has not been as extensively cultivated as its productiveness and promise would seem to justify.

EXERCISE XIX

EFFECTS OF PRACTICE—(*B*) MOTOR AND PERCEPTUAL HABITS

In order to modify a motor habit within the time required for this exercise, it will be necessary to begin with a process that is relatively little developed, and repeat it a large number of times. The undeveloped coördination referred to in Exercise XIV is a very good activity with which to work. Let a reactor who is slow and irregular in moving his fingers in the following order, index finger, middle finger, third finger, and little finger, make a series of several hundred of these movements in such a way as to secure a record of the duration of each pressure and of the intervals between the successive movements. In measuring these results, it is not necessary to measure every set of movements. Let five be measured at the beginning, then omit twenty and measure a second set of five, and so on throughout the whole record. Care should be exercised not to fatigue the reactor. Let inter-

vals of rest intervene whenever required to avoid fatigue.

Second, let a reactor trace over a simple pattern a number of times in succession, his hand and the pattern being seen by him not directly, but in a mirror. In this case the visual and motor factors involve nothing new or complex in themselves, but the normal relation between them is disturbed and must be readjusted. The results may be treated quantitatively by counting the number of corrective movements made by the reactor in attempting to follow the pattern, and by measuring the time required to make a complete tracing. The introspective record should show what the process of readjustment involves on the subjective side.

A third very simple method of studying the growth of organization in experience may be illustrated as follows: Take a pack of cards made up of a number of series, each series being marked with like figures. Distribute these cards into a number of piles corresponding to their several marks, measuring the time required for the performance. Repeat the distribution ten times, maintaining the same order among the various piles and shuffling the cards thoroughly between each distribution. A perceptual habit and a habit of move-

ment are thus formed. Now change the position of the various piles and, after shuffling the cards, make a new series of distributions, determining again the time required for each distribution.

This last experiment brings out very well the interference of habits. If a sufficient number of modifications in the order of arrangement of the piles is made, a measure can be secured of the degree in which this interference is itself modified by the larger development of experience.

Consider in the report the following questions:

What are the physiological changes which may be inferred to be parallel with these changes due to practice?

To what extent are the changes in the motor processes paralleled by changes in consciousness?

What practical advantages would result from a similar study of those ordinary motor processes which are trained in the course of individual education?

Certain extreme forms of motor development could be studied as follows:

Certain modes of action are fixed so that further practice does not seem to produce any effect; such, for example, are developed writing or walking.

How could change in these forms of action be induced?

When some wholly untrained activity is undertaken, how does it change with practice? For example, how does one learn to move his ears?

What is the effect of practice on the inhibition of certain reflex activities, such as the reflex winking of the eye on the rapid approach of some external object.

In addition to the activities suggested above, any form of motor dexterity, such as learning to use tools, learning to sew, to play a musical instrument, or to sing, could profitably be made subjects of investigation.

A convenient means of investigating the facts of practice is the typewriter. A record of the rate and correctness of performances is here easily obtained. Variations in the perceptual processes involved may easily be introduced by covering the keys with colors or figures and using them rather than the letters.

References which show some of the lines of work which have been undertaken along these lines are the article by Swift, given above, and the chapters on writing in the author's "Genetic Psychology for Teachers."

EXERCISE XX

DISTRACTION AND FATIGUE

As practice is constantly showing its effects in the results of psychological experiments, so certain negative effects frequently appear in what is called fatigue and distraction. The negative effects of fatigue and distraction are very difficult of demonstration because in ordinary activity there is a strong tendency to overcome negative effects by a greater effort on the part of the reactor. Experiments on these negative factors are, therefore, subject to very large variations. Experiments with distractions of various kinds usually yield results more readily than do experiments with fatigue. Whenever the concentration of attention upon a given action is interfered with by a second and irrelevant demand for the execution of movements, or when attention is diverted to some sensory experience not involved in the movement itself, the movement will show as well as does consciousness, the effects of distraction. The extent to which

the reactor is aware of the degree of interference with his movement varies greatly in different cases.

First, take graphic records of several series of taps, requiring the reactor to move his fingers at the greatest possible speed and allowing him in the first series perfect freedom to concentrate attention upon the movement. Then require him to execute a number of series of taps at the greatest possible speed, but require him during each series to count the beats of a metronome. Make the rate of the metronome beats first very slow, second very fast, and third medium. Record in each case the rate of the tapping. Also record the reactor's judgments as to the rate and regularity of his movements and the degree of influence of the distraction, if he notices any.

Second, instead of using a sound as a distraction, require the reactor to move his unengaged hand around a prescribed circle.

Third, require the reactor to read from a printed page.

Before each distraction series take a normal series. All series should be at least ten seconds long. In counting the series it is required that the num-

ber of taps in the first, the fifth, and the tenth second, be counted and tabulated.

Long-continued tapping is a good means of experimenting with fatigue. Measure the rate and regularity of tapping when the reactor begins such a series and at intervals throughout the series.

Other methods have been employed and will be mentioned among the additional problems outlined below.

The results of these tests should be given quantitatively.

Consider the following questions:

What relation is there between distraction and fatigue?

How do distraction and fatigue operate in the nervous system in affecting action?

Explain the relation between the effect of distraction and fatigue upon action and conscious recognition as shown by the reactor's introspections.

Similar experiments may be tried with tones. Let a record be made of the constancy with which a reactor can sound a tone. Distract him by re-

quiring him to sound some other tone and then return to the first. Require him in another case to hold a tone while listening to a second of different quality.

For tests of fatigue, require the reactor to lift a weight with one finger till the finger is completely fatigued. Determine the time required to induce such complete fatigue. Determine the effect of stimulating the general nervous system by encouraging the subject or by stimulating some organ of sense far removed from the reacting organ. Determine the effect of various periods of recuperation. Determine the effect on the amount of work done of the rate at which the work is attempted.

Use as the work to be done, not the lifting of a weight, but the addition or multiplication of numbers, or the marking out of all the s's or e's on a number of pages of printed matter.

The literature on fatigue is extensive. The following papers give some of the points of view:

Seashore, "Psychological Review Supplements," No. 28. "Studies in Voluntary Muscle Contraction," Stanford University Press, 1904.

Ellis and Shipe, "American Journal of Psychology," vol. xiv (1903), p. 232 [496].

References on distraction.

Drew, "Attention, Experimental and Critical," "American Journal of Psychology," vol. vii (1895), p. 533.

Darlington and Talbot, "A Study of Certain Methods of Distracting the Attention," "American Journal of Psychology," vol. ix (1898), p. 332.

Hamlin, "Attention and Distraction," "American Journal of Psychology," vol. viii (1896), p. 3.

INTRODUCTION
TO LAST FIVE EXERCISES

The experiments on practice, distraction, and fatigue have shown how certain general aspects of mental life may be approached through exact quantitative experimentation. To be sure, there are limitations to this kind of study. The distracting influence of a piece of bad news cannot easily be subjected to quantitative examination. Yet even where mental processes are not directly approachable in the laboratory, a preliminary study of one or more simple cases of a like kind will prepare the psychologist for more productive study of the complex cases which are open only to fortuitous observation. With this justification for the concentration of attention on simple cases of mental activity in its more general forms, the remaining exercises of the course will be devoted to experiments on certain forms of memory, attention and æsthetical appreciation, and complex ideational processes.

EXERCISE XXI

MEMORY

No mental process can take place without involving to some extent the observer's past experiences. In the general sense in which every present mental process is modified by past processes, experiments on perception and reaction, especially those dealing with practice, all involve memory. There is, however, a narrower sense in which the word memory is often used. In this narrower sense it refers to the recall in some detail of a specific past experience. Ebbinghaus was the first to subject memory in this sense to an elaborate experimental investigation, and this exercise will follow the method used by him.

Prepare a series of nonsense syllables, that is, syllables which are made up in each case of a consonant, a vowel, and a second consonant, and do not form a word, or a combination closely related to a word. Let an observer perceive a series of such syllables, either (*a*) by reading them over silently,

or (*b*) by reading them aloud, or (*c*) by having them read to him. After he has gone through the series once, an approximate measurement of how much he has retained may be secured by requiring him to reproduce as much of the series as he can. A better procedure is to present the series a second and a third time, requiring the observer to anticipate, if he can, each syllable just before it is given. As soon as the observer can, in this way, anticipate every syllable in the series before it is given, he is considered, for the purposes of the experiment, to have memorized the series. The number of readings required to memorize a series is noted as the measure of the effort involved. By this method make the following determinations:

1. Which is the more advantageous method of learning a series of nonsense syllables, to read the series silently, to read it aloud, or to hear it read?

2. How much is retained of a series after fifteen minutes, and how much after an hour?

3. Take series of different lengths, of ten, fifteen, twenty, and twenty-five syllables, and determine the relative amount of effort involved in memorizing each series.

In the report consider the advantages and disadvantages of using nonsense syllables in experiments on memory.

Consider especially, in view of the results obtained in the second part of the experiment, whether there are any stages of memory before complete recall.

Why should the quality of the impression affect the memory?

While nonsense syllables furnish an exact method of measuring memory, other sensory impressions and other objects of perception may be employed. Thus, sound a tone on the monochord, and then sound another like the first, or slightly different from it. Repeat this test, proceeding by the method of gradual change until the limit of error in memory is determined by finding how great must be the difference between two tones, in order that the subject may retain enough of the first tone to make an accurate comparison with the second, and recognize with certainty that it is different from the first. The time intervals between the standard and comparison tone may be varied as much as is desired to determine the effects of lapse of time on the ability to retain tones.

Memory for lines and figures may be tested by showing the subject a line or simple figure, and after a time requiring him to reproduce what has been shown him, or to recognize with accuracy whether a second line or figure is the same as the first, or different.

An analysis of the factors which contribute to the process of memorizing may be made by repeating an experiment performed first by Münsterberg. Let a subject learn a series of words or nonsense syllables without in any way interfering with his natural method of learning. In a second series use like material, but interfere with the natural tendency to articulate what is being learned by requiring continual articulation of some simple irrelevant sound such as *ah*. The result of the second series, as compared with the result of the first, will show the unfavorableness of the second condition in a definite quantitative way.

For a general summary, see Kennedy, "Psychological Review," vol. v (1898), p. 477.

EXERCISE XXII

FLUCTUATIONS OF ATTENTION

Attention is a general term used to indicate that certain mental processes are of a high degree of vividness. Vividness is due to a variety of causes. In some cases it is closely associated with intensity of sensory impressions. In some cases there are marked motor adjustments which constitute its most obvious accompaniment. In this exercise the relative effects of various forms of voluntary attention are subjected to measurement, and the opportunity is offered to the observer of undertaking, introspectively as well as objectively, an analytical study of the conditions and results which characterize attention.

First, set up a drawing which is capable of being interpreted as a solid or as a hollow object, and require an observer to change as fast as possible from one interpretation to the other, recording at the same time the duration of each phase of interpretation. Determine in this way the rate at which

change from one interpretation to the other can be made twenty times in immediate succession. Then make a second series, requiring the observer in this case to retain for as long a time as possible the interpretation of hollowness. In a third series, let the observer try to concentrate on the solid interpretation. Full introspective records should accompany the time records.

Second, set up a stereoscope with plain fields of red and green presented to the right and left eye, respectively. Record, as in the foregoing series, the rate of rivalry when the attention is equally concentrated on both, and when an effort is made to emphasize first one and then the other.

Third, set up a Masson disk and record the rate at which the ring which is at the limit of perceptibility appears and disappears.

In the report, make a general quantitative comparison between the fluctuations of attention found in all these various cases.

Discuss the cause of fluctuations and the causes of variations in the rate of fluctuation.

Relate the discussions in this report to the results of Exercises XII, XIII, and XV in this course.

Additional experiments on attention have been suggested in connection with a number of the earlier exercises, and the following exercise will continue this line of investigation.

A good experimental study of the subject taken up in the second part of this exercise is Breese's paper, "On Inhibition," in the "Psychological Review, Monograph Supplement, No. 11." Some excellent theoretical and experimental discussions are presented by MacDougall in the paper entitled "The Physiological Factors of the Attention Process," "Mind," N. S., 1902–6, vol. xi, p. 316; vol. xii, pp. 289, 473; vol. xv, p. 339.

EXERCISE XXIII

SCOPE OF ATTENTION AND CONSCIOUSNESS

Arrange conditions such that an observer receives an auditory stimulation while looking at a pointer moving over a graduated scale. Let him try to determine the exact position of the pointer at the moment when the auditory impression is given. Let the error be measured under various conditions: (*a*) when the pointer is moving rapidly, (*b*) when it is moving more slowly, (*c*) when the sound is very faint, and (*d*) when the sound is loud.

Present to the observer for a very short interval an elaborate visual field, as, for example, a field full of letters arranged in miscellaneous order. Determine how much he recognizes clearly in the interval of exposure and how much he recognizes vaguely. Repeat, using combinations of letters which form significant words.

Produce a series of six to twelve sounds in rapid succession, under conditions such that the rate and number of sounds can be regulated, and require an

observer to attend to the series of sounds, but not to count the strokes. Now require the observer to reproduce the series and take a record of the reproduction. If the reproduction is correct, gradually increase the number of sounds so as to determine the limit of the observer's ability to recognize the series. Vary the character of successive series by making some consist of rhythmical groups of sounds, rather than uniform successions of sounds.

In the report consider the relation between the total scope of consciousness and the more limited field of attention.

How many impressions can be held at one time in the attention? Supplement the experimental results by an appeal to the experiences of ordinary life.

The whole question of the perception of time may be taken up as a supplement to this exercise. Experiments on time require an elaborate technic, and to gain productive results they should be carried on for a longer period than that allowed for each of the exercises of this course. By means of some mechanical device, mark off intervals of time with clear sensory stimuli. Measure by com-

parison the accuracy of estimation of time intervals of different lengths. Vary the stimuli so as to have some of strong and some of weak intensity. Fill certain intervals with continuous sound or light stimulation and compare these with unfilled intervals. In this connection consider the facts of time perception as illustrated in versification.

The experiments outlined in this exercise involve a great variety of questions. The following references may be consulted to bring out further questions and modifications of the experiments.

Wundt, "Outlines of Psychology," pp. 231–36.

Pierce and Angell, "American Journal of Psychology," vol. iv (1891), p. 528.

EXERCISE XXIV

ÆSTHETIC APPRECIATION

The feelings, and especially the higher emotions, have always constituted a difficult sphere of psychological study. Conditions are complex, and the means of determining the character and extent of affective mental states are very meagre. Even the ordinary descriptions of our feelings reflect the vagueness of these states and the difficulty of observing them. Some progress has recently been made in the investigation of emotions by a careful investigation of expressions. The methods and results of such studies have been exhibited in earlier exercises. It remains to illustrate a somewhat different type of investigations in this exercise. The æsthetical appreciation of forms is a typical emotional experience which can be reduced to relatively very simple terms, and methods have been devised for the study of the principles which underlie certain simple cases of such appreciation.

Arrange a uniform field of vision through the central part of which there extends a simple horizontal line. Require the observer to divide this line by means of an adjustable cross-line at some point other than the centre, so that the two parts of the divided line shall seem to him to stand in an agreeable relation. Repeat the division five times on each side of the centre and measure the relation between the parts.

Second, arrange a cross in a uniform visual field. Let one leg of the cross be set at various lengths, and require the observer to set the other leg in such positions and of such lengths as shall seem to him to make the whole figure most agreeable. Measure the relations which result.

Third, arrange a uniform visual field and place in it a central point of reference, and at a fixed distance on the right draw a short vertical line five centimetres in length and one millimetre in width. Require the observer to place on the left of the central point a succession of figures, such as short lines, squares, colored irregular and regular figures, at distances which seem necessary to him in order that the result may be a well-balanced group of figures. Determine in this way what is the rela-

tion of balance to variations in size and to variations in form and color.

In all of these experiments require the observer to study introspectively his experiences.

In the report combine the introspections with the measurements and discuss the following questions:

Can æsthetical appreciation be explained by reference to facts of sensation; such, for example, as sensations of eye-movement?

Is "balance" a principle capable of any general formulation? On what does it depend?

Do these experiments throw any light on the complex appreciations which cultivated individuals experience in the presence of works of art?

Further experiments may be devised along the lines suggested in this exercise as follows:

Vary the direction of the lines to be divided.

Use as an adjustable figure, not the cross, but a rectangular figure, one of whose dimensions is given, the other to be set to suit the observer.

In the experiments on balance use complex figures, such as groups of words, or significant figures which have intrinsic interest.

A variation in method may be introduced in these

experiments by presenting to the observer a great variety of ready-made combinations in crosses, oblong figures, etc., and asking him to select the one in each group which most adequately meets his taste. This is known, in general, as the method of selection, rather than the method of adjustment used in the exercise.

The method of selection may be used in determining the color or tone which is most agreeable to any given individual or group of individuals.

Experiments in æsthetics of the type here described were first outlined by Fechner (1876) in his book entitled "Vorschule der Æsthetik." Reports of studies will be found in Witmer's "Analytic Psychology," pp. 61–88, and in the "Harvard Psychological Studies," which appeared as No. 17 of the "Psychological Review Monograph Supplements," pp. 309–561.

EXERCISE XXV

EXPERIMENTATION WITH COMPLEX MENTAL PROCESSES

An exceptionally clear illustration of the application of experimental methods to the study of a complex mental process is to be found in a paper by Prof. O. Külpe, published in "Philosophische Studien," in 1902, under the title "Ueber die Objectiverung und Subjectiverung von Sinneseindrücken" (see p. 508). The method and the problem are introduced into this series of exercises in order that they may serve to suggest extensions of the domain of experimental psychology.

One of the most complex facts of mental life is that every individual refers certain of his mental experiences to the external world and others to his purely personal, subjective world. The matter may be made a subject of experimental investigation by arranging conditions under which the observer will have some difficulty in deciding whether his experiences are to be referred to the outer world or to the subjective world. Such conditions were

arranged by Külpe by placing the observer in a dark room and projecting from time to time on the wall before him a faint light. The observer in the meantime was to give a full account of all his light experiences and the degree of certainty which he felt with regard to their objective or subjective reference. A comparison was then instituted between the true objective conditions and the observer's references.

The results of such a series of observations are of much greater value than any purely theoretical discussion of the matters involved, and the conditions can be repeated with as great a number of observers as desired, so that the general principles of objective reference may be made out on a broad basis of carefully defined observations. The experimental conditions are not elaborate, and yet they indicate a marked advance on the non-experimental procedure in like inquiries.

A second investigation to which reference may be made in this connection is one by A. E. Davies, reported in the "Psychological Review" of March, 1905, p. 166. The problem was to determine experimentally what the first conscious process of the subject would be when he was allowed to observe figures of various forms and degrees of illumina-

tion exposed in a dark room. The figures came suddenly into the field of vision, and the observer was required to react with a simple movement to each figure as it appeared. He was also required to record as fully as possible all of the accompanying experiences which he passed through in forming a clear recognition of the figure.

The introspections of the subjects are presented in detail in Davies's report, and he makes these introspections the basis of the theoretical discussion of what he calls "the elementary psychic process." The advantages of such an investigation are that the observations of the subjects can be repeated a number of times under definable conditions, and the conclusions from various subjects can be compared on something like a uniform basis.

END

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